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(b) A CASE FOR SURVIVAL DEEP UNDERGROUND*

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A CASE FOR SURVIVAL DEEP UNDERGROUND

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Military systems and government agencies whose mission and functions require continued operations in wartime and whose activities can be made compatible with a deep underground environment should be designed in the future with the following premise in mind: SURVIVAL FROM VERY IMPRESSIVE ATTACK IS FEASIBLE AT PRACTICAL DEPTHS OF COVER.

Survival obviously means that the cavity containing the installation does not collapse and that no violence is done to the contents, thus stresses in the earth material around the installation must be well below the crushing strength of the surrounding rock or cavity liner, and the shock spectrum must be characterized by manageable accelerations and motions. Crushing strengths for hard rocks may run as high as several kilobars,^{*} and accelerations of many times that of gravity (many "g's") can be accepted if they are delivered at high frequencies--even at a few cycles per second, accelerations of several g's might be considered manageable.

An impressive attack should encompass the possibility of a number of weapons of high accuracy and high yield. Although it is important in assessing the survivability of any installation to look hard at the future developments in weapons for five to ten years hence, we could consider an attack with zero CEP and 100 MT yield to be very impressive at any time.

Practical depths of cover must be defined in terms of availability of sites, cost of construction, and operational feasibility, but current geologic studies indicate many potential sites; past mining, tunneling and underground construction experience indicates cost estimates can be

^{*}(One Kilobar = 14,500 psi.)

made both reasonable and reliable, and a surprising number and variety of military roles have already been proven capable of operation from sites located two or three thousand feet deep--under mountains or below level stratum.

Although rigorous justification of this statement about survival would be required before costly and extensive deep underground construction is begun, we will be content here to indicate in general terms the basis for such a position. Recent investigations⁽¹⁾ have led to a better understanding of the initiation of the intense ground shock in the immediate vicinity of an explosive source. The initial shock is shown to decrease in intensity very rapidly with increasing penetration to depth due both to the geometric effects of expanding into the ground behind a hemispherical wave front and venting into the air above the surface and to the intense dissipation in the strong shock region (Fig. 1). Beyond the strong shock region the geometry of a near-surface burst continues to require a fairly rapid decay, and dissipations and dispersions due to layering, faulting and irreversible heating in the crushed, cracked and distorted material must continue to sap the shock strength, so that after traversing several thousand feet of rock, the peak stress from even a most impressive attack be reduced below the dangerous level. Counting on some stress amplification at the cavity walls, the stress level in the rock should be kept below one-third the crushing strength. In Fig. 2 the peak stress is shown approximately as a function of depth for three yields and for a range of rock hardness. These curves are meant to be illustrative of an idealized rock medium, stress levels could be both higher or lower dependent on details of weapon delivery and rock properties, but realistic account of the dissipation features should force the stress levels to fall

well below the levels indicated here.

Even with the cavity remaining intact, the contents must be insulated from extremes in accompanying accelerations and motions. It is the nature of natural materials to absorb the high frequency components of the shock-spectrum quite rapidly, so that the most serious motions will come at low frequencies and long wave-lengths. While these may cause transient displacements of a few feet, the accelerations should be modest (a very few g's, or less with appropriate isolation). It is fair to note that shock mounting for low frequency motions requires massive systems and so more costly construction, hence it will be important to define accurately the expected shock-spectrum, not from the standpoint of determining the feasibility of survival but for the purpose of minimizing the expenses of extensive shock isolation.

The various requirements for openings to the exterior for equipment, personnel and communications need not compromise the survivability of the deep site, since redundancy, and a number of practical positive closure schemes can provide alternative exits while retaining isolation for the main installation. In any event, an opening can be made to survive nearly anywhere outside the crater and lip of a nuclear explosion.

The "water door"⁽²⁾ or similar schemes can provide removable closures to withstand shock pressures in the thousands of psi. Alternately, tunnels left open for normal operation can be blasted closed in time to prevent shock entrance--using simple blast switch triggering and pre-placed explosive charges. With appropriate attention to detail, self-sealing entrances can be arranged, such that the nuclear blast itself can cause closure before blast can enter the tunnels. To further insure exit

survival, excavations to the surface from inside can be carried to within one or two tunnel diameters of the surface. The unexcavated remainder would then be drilled and prepared in advance for removal at the appropriate post-attack time.

Post attack ventilation and communications problems can be met in a variety of ways using multiple or alternate protected connections to the outside world. For air intake or exhaust, where heavy diesel power requirements exist, careful design can provide large-volume air-flow at low velocities at the same time preventing the entrance or propagation of high pressure shocks from outside. Where appropriate, nuclear reactors can provide power without the attendant air and exhaust problems of diesels. Although all communications hardening problems have not been solved, there is good reason not to pin the hardness of the central installation to any current "weakest links." Much improved survival can be expected from retro-fitting to take advantage of future advances in design, but only if the main functioning centers are insured survival by their initial super-hard positioning.

The salient feature of design to withstand direct hits stems from the position an enemy attack planner is forced to take regarding kill probabilities. Where the "cut-and-cover," finite hardness installation can be guaranteed "dead" whenever a weapon lands and explodes close enough to collapse or to crater that target, an installation with more than two thousand feet of cover cannot be directly "hit" or cratered even with a direct hit. Reducing CEP's, raising yields, or using large numbers of weapons cannot remove the uncertainty in the enemy kill criteria for such a site, and he may be thus forced to concentrate on other aspects of the

system or on less direct and more elaborate schemes for attack. On the other hand, his answer to the "cut-and-cover" need only be to concentrate on reducing CEP's, to raising the yield of his attacking weapons, or to employing more of them, and with small enough CEP's he needs neither a large number nor a large yield!

Although the superhard concept has these clear advantages, it offers no panacea to problems of protecting strategic installations in general. In the first place we are speaking of depths of a few thousand feet rather than a few hundred feet. In the second place, we are concerned only with the one-of-a-kind or few-of-a-kind situation, since costs, site selections and operational limitations would preclude full application to a weapon system of many protected sites.

We recommend the deep underground concept for vital targets whose survival from even a direct hit is of utmost importance. It should be considered in situations where the successful completion of the mission of an entire weapon system or of a large fraction of a force depends on the continued operation of one or a very few centers. Such centers must appear as important targets to a determined enemy and can be made less attractive to him only by making them relatively safe from a frontal attack--by making them superhard--by sinking them below a feasible cratering depth.

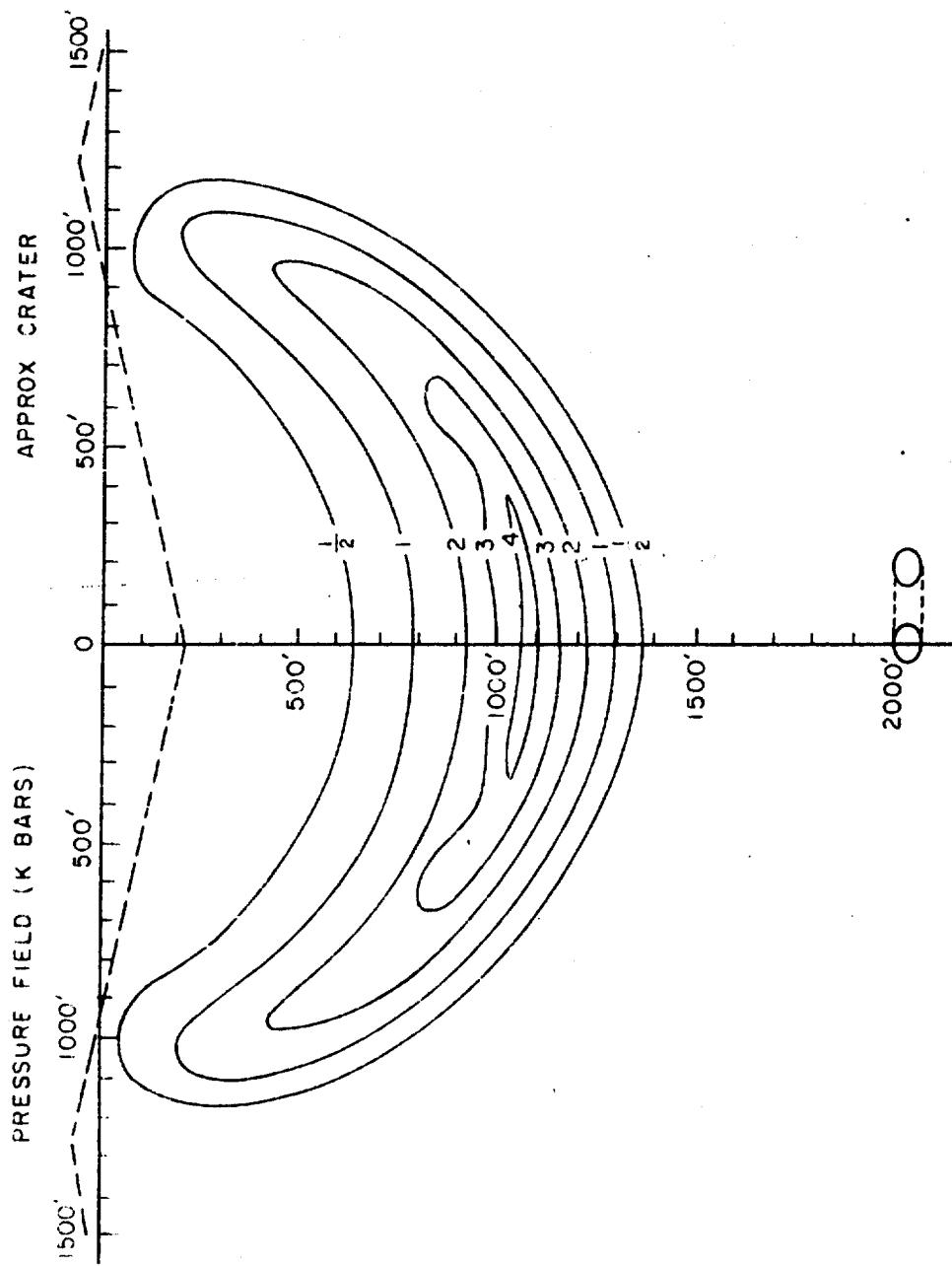


Fig. 1.—Ground shock from 10 M.T. surface burst (at ~ 43 ms)

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SURFACE BURSTS ON ROCK

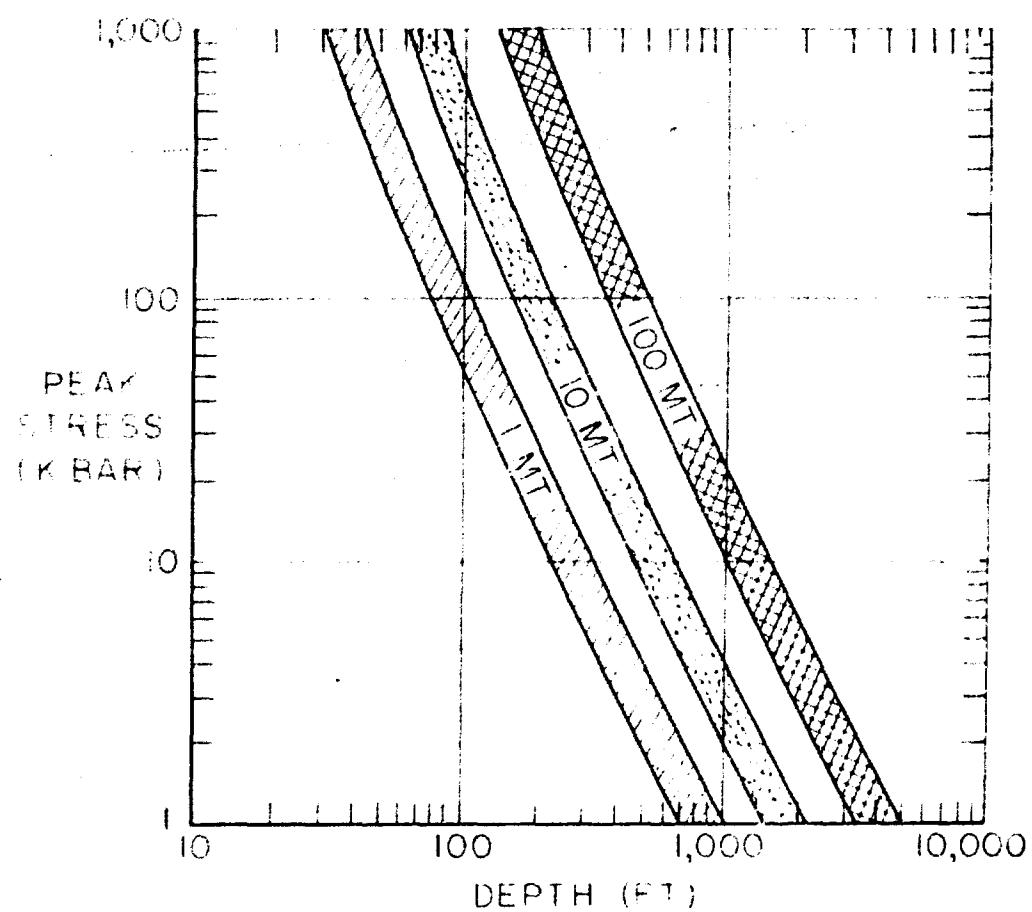


Fig. 2

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